U.S. PATENT APPLICATION

for

USING DEUTERATED SOURCE GASSES TO FABRICATE LOW LOSS GeSiON SiON WAVEGUIDES

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FIELD OF THE INVENTION

[0001] The present invention is directed generally to the manufacture of optical waveguides and more particularly to the use of deuterated source gasses to manufacture optical waveguides.

BACKGROUND OF THE INVENTION

[0002] Practical optical devices must be fabricated so as to direct the light energy. Commonly, this is achieved by creating a waveguide. In the waveguide, a cladding layer of lower refractive index (typically 1.44) directs light by internal reflectance to an optical core of higher refractive index (typically 1.45-1.5). Both the core and cladding layer can be made from many different materials. Common materials include glasses of SiO_2-GeO_2, SiO_2-B_2O_3-P_2O_5, SiO_2-GeO_2-B_2O_3-P_2O_5, SiO_2 and SiON. Silicon dioxide, silicon nitride and silicon oxynitride are materials which are particularly valued for their optical properties, in particular their high optical transparency and wide range of refractive indices (1.45-2.5). These materials are used in a host of optical devices. The devices include, for example, planar waveguides, arrayed waveguides (AWG), wavelength demultiplexers, power splitters, optical couplers, phasers, and variable optical attenuators (VOA).

[0003] Typically, chemical vapor deposition (CVD) is used to deposit layers of silicon dioxide, silicon nitride or silicon oxynitride. In the CVD process, the substrate is placed on a heated susceptor in a quartz reaction chamber and then the reactant gases are introduced into the chamber. Typically, the gasses react on the surface of the substrate and form a deposited layer. However, some reactions may also occur as the gasses flow into the chamber. The most common gasses for the deposition of silicon dioxide, silicon nitride and silicon oxynitride are silane (SiH_4), chlorinated silane (SiH_xCl_{4-x}), nitrous oxide (N_2O),

ammonia (NH_3) and nitrogen (N_2). These gases are inexpensive and can be purchased in great abundance.

[0004] Although the CVD process is the preferred process for depositing many of the materials used to manufacture optical devices, it is not without problems. The use of ammonia and silane in the production of silicon nitride and silicon oxynitride results in the incorporation of large amounts of hydrogen (up to 20 at% for silicon nitride) in the optical film.

[0005] The incorporated hydrogen generates significant optical losses at the 1550 nm optical communication band due to a strong overtone of the N-H bond. Figure 1 illustrates the loss spectrum of conventionally processed silicon oxynitride, i.e., the loss over a range of wavelengths. The peak in loss is due to N-H absorption. In conventional manufacturing processes, the silicon oxynitride contains a significant amount of hydrogen. The figure clearly illustrates the deleterious effect of the overtone of the N-H bond. The center of the loss peak occurs at a wavelength of approximately 1510 nm. This is just 40 nm from 1550 nm, a preferred optical communications wavelength.

[0006] It is possible to remove much of the entrapped hydrogen with high temperature thermal annealing. However, the optical SiON film can blister and crack at the high temperature, rendering the device useless.

[0007] Therefore, it would be desirable to develop a method to manufacture optical devices which did not result in the incorporation of hydrogen in the optical SiON film and high losses at 1550 nm. Furthermore, it would be desirable to develop a process having the benefits of the speed and control of the conventional CVD process without resorting to a high temperature anneal to drive out the hydrogen.

SUMMARY OF THE INVENTION

[0008] The present invention provides a method of manufacturing optical devices comprising providing a substrate and forming at least one optical layer on the substrate by a CVD process including at least one deuterated source gas.

[0009] The present invention also provides an optical device comprising a substrate and an optical layer including deuterium.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The foregoing and other features, aspects and advantages of the present invention will become apparent from the following description, appended claims and the exemplary embodiments shown in the drawings, which are briefly described below. It should be noted that unless otherwise specified like elements have the same reference numbers.

[0011] Figure 1 is a plot of the loss spectrum of silicon oxynitride in the vicinity of the N-H absorption peak.

[0012] Figure 2 is a plot of the FTIR spectra of GeSiON films deposited with ND_3 and with NH_3.

[0013] Figure 3 is a cross section of an embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014] The present invention is directed to reducing the optical transmission loss in a waveguide by reducing the hydrogen content in the waveguide. Figure 3 shows the cross section of a planar waveguide manufactured according to a preferred embodiment of the present invention. In this embodiment, an insulating buffer layer 102 is deposited on a substrate 101. A waveguide core 103 including deuterium is then deposited on the buffer layer 102 and the entire structure is coated with a cladding layer 104. As demonstrated below, the use of deuterated source gasses is effective in reducing the hydrogen content of the waveguide.

[0015] Silicon is the preferred material for the substrate 101. However, the substrate 101 may be made out of any material suitable for supporting the waveguide core 103. Example substrate materials include, but are not limited to, GaAs, InP, SiO_2, Si_3N_4, ceramics and plastics.

[0016] The preferred material for the buffer layer 102 is silicon oxynitride (SiON) or germanium doped silicon oxynitride (GeSiON). More preferably, the

material for the buffer layer 102 is deuterated silicon oxynitride (SiON) or deuterated germanium doped silicon oxynitride (GeSiON). Additional materials suitable for the buffer layer include fluorine doped silica (FSG), phosphorous doped silica (PSG) and boron and phosphorous doped silica (BPSG). However, any suitable material can be used. For optimum results, the buffer layer 102 should have an index of refraction less than the index of refraction of the waveguide core 103. The buffer layer 102 may be omitted if the substrate is formed from a suitable material with a lower index of refraction than the core.

[0017] The preferred material for the cladding layer 104 is SiON or GeSiON. More preferably, the preferred material for the cladding layer 104 is deuterated SiON or deuterated GeSiON. However, any suitable material, such as plastics for example, can be used. For optimum results, the cladding layer 104 should have an index of refraction less than the index of refraction of the waveguide core 103.

[0018] The core 103 of the optical waveguide preferably comprises deuterated germanium doped silicon oxynitride ($Ge_wSi_zO_xN_y$), where the sum of w, x, y and z is equal to 1. More preferably, the core 103 comprises deuterated silicon oxynitride ($Si_zO_xN_y$), where the sum of x, y and z is equal to 1. The deuterium replaces hydrogen and thereby reduces the hydrogen content in the waveguide. The index of refraction of the core is preferably between 1.44 and 2.2. More preferably, the index of refraction of the core is between 1.6 and 1.8. Furthermore, transmission losses due to attenuation are preferably less than 4.0 dB/cm in multimode slab waveguides and less than 2.0 dB/cm in single mode slab waveguides. More preferably, the transmission losses due to attenuation are less than 1.5 dB/cm in multimode slab waveguides and less than 0.2 dB/cm in single mode slab waveguides at 1550 nm.

[0019] By using deuterium source gasses in manufacturing the core 103, the hydrogen content of the core 103 is reduced and consequently the optical loss is reduced. This is shown, for example, by the Fourier transform infrared (FTIR) spectra of germanium doped silicon oxynitride (GeSiON) films are illustrated in Figure 2.

[0020] A film deposited with NH_3 is represented by the bottom spectrum in Figure 2. This spectrum shows, like Figure 1, that the NH stretch is at 3310 cm-1 (3.02 μm), which places the overtone absorption peak approximately at 1510 nm, which is near the communications wavelength. In contrast, the top spectrum in figure 2 represents a the germanium doped silicon oxynitride film formed with deuterated ammonia (ND_3) instead of regular ammonia (NH_3). As shown, the absorption peak is shifted from 3.02 μm to 4.08 μm. The overtone peak therefore shifts to 2004 nm, far from 1550 nm, the optical communications wavelength, by substituting ND_3 for the NH_3 source gas during deposition.

[0021] The use of deuterated silane, deuterated disilane and deuterated germane produce similar results. The use of any of these gases alone or in combination is beneficial because losses at 2004 nm due to the N-D bond are not significant for communications at 1550 nm.

[0022] The use of the deuterated core material has been described and illustrated by way of an optical waveguide. However, this is but one device which can be fabricated according to the present invention. Other devices which may also benefit from the material of the present invention include, but are not limited to, an optical waveguide, an arrayed waveguide, a wavelength demultiplexer, a power splitter, an optical coupler, a phaser, and a variable optical attenuator.

[0023] The core of the optical waveguide is preferably deposited by chemical vapor deposition (CVD). Low pressure CVD (LPCVD), atmospheric pressure CVD (APCVD) and plasma assisted CVD (PECVD) can be used. However, PECVD is the preferred method. One example of PECVD deposition is described below.

EXAMPLES

[0024] Deuterated silicon oxynitride and deuterated germanium doped silicon oxynitride films were deposited with an STS Multiflex PECVD system. This system is a parallel plate reactor where the precursor gasses enter through an

array of holes in the top electrode (showerhead) and the sample rests on the bottom electrode. The bottom electrode is a non-rotating heated platen. The reaction gases included silane (SiH_4), germane (GeH_4), nitrous oxide (N_2O), deuterated ammonia (ND_3) and nitrogen (N_2). Regular ammonia (NH_3) was also available for making the comparative examples. The refractive index, optical propagation loss and film thickness were determined with a prism coupling system.

[0025] An initial series of thin germanium doped silicon oxynitride films were deposited with and without deuterated ammonia to evaluate the reduction in waveguide loss. These films were deposited on Si(100), SiO_2 and Corning 1737 glass substrates to form multimode slab waveguides. The deposition parameters for these films are in Table 1.

TABLE 1

Recipe ID	EX. A	EX. B	EX. C	EX. D	EX. E	EX. F
Rf (380kHz) Power (W)	400	400	400	400	400	400
Pressure (mtorr)	500	400	400	400	500	400
Substrate Temperature (C)	350	350	350	350	350	350
Showerhead Temperature (C)	225	225	225	225	225	225
5% SiH_4/Ar (sccm)	200	100	100	200	200	100
2% GeH_4/Ar (sccm)	250	400	400	250	250	400
N_2O (sccm)	200	117	117	200	200	117
ND_3 (sccm)	200	50	100	300	0	0
NH_3 (sccm)	0	0	0	0	200	50
N_2 (Sccm)	1600	2000	2000	1600	1600	2000
Deposition Time (min)	40	40	40	40	40	40

[0026] Films from the initial round of GeSiON films with ND_3 were smooth and uniform with a slight green coloration as deposited. The film thicknesses

and indexes were measured by prism coupling at two wavelengths, 652 nm and 1550 nm. The prism coupling measurements demonstrate that the thickness and indexes are very near that of films deposited with NH_3. Table 2 summarizes the thickness and index measurements.

TABLE 2

	n(632) nm	t(632) μm	N(1550) nm	t(1550) μm	t(ave) μm
EX. A	1.6732	3.6012	1.6482	3.5616	3.5814
EX. B	1.7398	3.3384	1.7105	3.3607	3.3496
EX. C	1.8308	3.2623	1.7897	3.2462	3.2543
EX. D	1.7073	3.2744	1.6819	3.1631	3.2188

[0027] Table 3 is a comparison between attenuation measurements on multimode slab germanium doped silicon oxynitride waveguides deposited with ND_3 (Examples A to D) and multimode slab germanium doped silicon oxynitride waveguides deposited with NH_3 (Examples E and F).

TABLE 3

Sample	Loss in dB/cm
EX. A	2.5
EX. B	2.1
EX. C	3.5
EX. D	1.3
EX. E	8
EX. F	11

[0028] The optical propagation loss in multimode slab waveguides ranged from 1.3 to 3.5 dB/cm for films deposited with ND_3. By comparison, the propagation loss in comparable films deposited with NH_3 ranged from 8-11 dB/cm.

[0029] Table 4 summarizes and compares the compositions of the GeSiON films deposited with ND_3 with those deposited with NH_3.

TABLE 4

Atomic Fraction							
Sample		Si	Ge	O	N	H	D
EX. E	NH_3	0.184	0.087	0.295	0.250	0.184	-
EX. A	ND_3	0.153	0.104	0.317	0.190	0.086	0.150
EX. F	NH_3	0.121	0.196	0.425	0.149	0.109	-
EX. A	ND_3	.0.93	0.228	0.377	0.122	0.090	0.090

[0030] The samples prepared with ND_3 have significantly less hydrogen incorporation than the samples prepared with NH_3. Samples deposited with ND_3 show lower nitrogen levels. This is believed to result from a lower ND_3 flow than NH_3 because the flow controllers were not re-normalized.

[0031] A second series of thin germanium doped silicon oxynitride films were deposited with deuterated ammonia to evaluate the reduction in waveguide loss. In this series, two samples were deposited with a waveguide core over a 13-15 μm cladding layer on a silicon wafer to form a single mode waveguide. The deposition parameters are summarized in Table 5

TABLE 5

	G		H		I		J	
Recipe ID	Underclad	Core	Underclad	Core	Underclad	Core	Underclad	Core
Rf (380kHz) Power (W)	400	400	400	400	400	400	400	400
Pressure (mtorr)	400	400	400	400	400	400	400	400
Substrate Temperature (C)	350	350	350	350	350	350	350	350
Showerhead Temperature (C)	225	225	225	225	225	225	225	225
5% SiH_4/Ar (sccm)	100	100	100	100	100	100	100	100
2% GeH_4/Ar (sccm)	400	400	400	400	400	400	400	400
N_2O (sccm)	125	117	125	117	125	117	125	117
ND_3 (sccm)	50	50	50	50	0	0	0	0
NH_3 (sccm)	0	0	0	0	50	50	50	50
N_2 (Sccm)	2000	2000	2000	2000	2000	2000	2000	2000
Deposition Time (min)	135	40	160	60	135	40	160	60

[0032] As in the initial series of films, the film thicknesses and indexes were measured by prism coupling at two wavelengths, 652 nm and 1550 nm. The prism coupling measurements demonstrate that the thickness and indexes are very near that of films deposited with NH_3. Table 2 summarizes the thickness and index measurements.

TABLE 6

		n(632) nm	t(632) μm
EX. G	Clad	1.6875	13.4047
	Core	1.6997	6.5692
EX. H	Clad	1.6916	16.0999
	Core	1.7007	6.6219

[0033] Table 7 is a comparison between attenuation measurements on single mode slab germanium doped silicon oxynitride waveguides deposited with ND_3 (Examples G and H) and single mode slab germanium doped silicon oxynitride waveguides deposited with NH_3 (Examples I and J).

TABLE 7

Sample	loss in dB/cm
EX. G	1.3
EX. H	2.0
EX. I	7
EX. J	7

[0034] The optical propagation loss in single mode waveguides ranged from 1.3 to 2.0 dB/cm for films deposited with ND_3. By comparison, the propagation loss in comparable films deposited with NH_3 was 7 dB/cm.

[0035] A third series of deuterated thin film single mode waveguides were manufactured to study the effect of various GeSiON/SiON core/cladding configurations. In this series, three combinations were tested. These include,

GeSiON core/clad, SiON core/clad and SiON core on GeSiON clad. The deposition parameters are summarized in Table 8.

TABLE 8

	K		L		M		N	
Recipe ID	Under -clad	Core	Under-clad	Core	Under -clad	Core	Under -clad	Core
Rf (380kHz) Power (W)	400	400	400	400	400	400	400	400
Pressure (mtorr)	350	350	350	350	350	350	350	350
Substrate Temperature (C)	350	350	350	350	350	350	350	350
Showerhead Temperature (C)	225	225	225	225	225	225	225	225
5% SiH_4/Ar (sccm)	100	100	260	260	100	260	100	0
2% GeH_4/Ar (sccm)	400	400	0	0	400	0	400	0
5% SiD_4/Ar (sccm)	0	0	0	0	0	0	0	260
N_2O (sccm)	125	120	35	35	126	35	126	33
ND_3 (sccm)	45	45	60	60	45	75	45	100
N_2 (Sccm)	3500	3500	3500	3500	3500	3500	3500	3500
Deposition Time (min)	160	60	205	55	165	57	165	90

[0036] In the third series, both the propagation loss and the wafer warpage was measured. The result of these experiments are summarized in Table 9.

TABLE 9

Sample	Loss in dB/cm	Wafer warpage TIR (μm)
EX. K	1.12	20.5
EX. L	<0.2	217.8
EX. M	0.38	8.0
EX. N	<0.2	121

[0037] The first sample (Example K), a GeSiON core on a GeSiON cladding layer, exhibits approximately a 1 dB/cm propagation loss with low wafer warpage. The second sample (Example L), a SiON core on a SiON cladding layer, had a propagation loss near the 0.2 dB/cm detection limit of the test

equipment. However, the wafer warpage is very high. Depositing a SiON core on a GeSiON cladding, the third sample (Example M), resulted in a slightly higher loss of 0.38 dB/cm while reducing wafer warpage. Depositing a SiON core on a GeSiON cladding using deuterated ammonia and deuterated silane, the fourth sample (Example N), resulted in propagation losses below 0.2 dB/cm. However, wafer warpage increased significantly.

[0038] The foregoing description of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of the invention. The drawings and description were chosen in order to explain the principles of the invention and its practical application. It is intended that the scope of the invention be defined by the claims appended hereto, and their equivalents.

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